New Brunswick Department of Municipal Affairs and Environment

Technical Report Series No. T-88-03

PHOSPHORUS MODELLING

GREENHILL LAKE, 1987

Environmental Sciences Branch

June 1988

1. Introduction

In continuation of previous studies, phosphorus monitoring of Greenhill Lake was conducted during the period November 1, 1986 to October 31, 1987. Methods were the same as these described in N.B. Dept. of Municipal Affairs and Environment (1987). Phosphorus dynamics were again calculated relying primarily on the model described in Dillon and Rigler (1975).

Samples were collected on 86 days during the period, with the most intensive effort occurring from July to mid-October when samples were taken on an almost daily basis Monday through Friday.

Flows were again prorated from the hydrometric gauging station at Hayden Brook and phosphorus values for days when sampling was not done were estimated by interpolation. Flows and phosphorus concentrations were then used to calculate phosphorus loading at the inlet and export at the outlet.

2. Calculation of Annual Phosphorous (P) Supply

(a) The average flow in Hayden Brook for the study period was 0.1107 m^3/sec or 3,491,035 m^3/yr.

Multiplying by the proration factor of 0.71296 resulted in an annual volume of 2,488,968 m^3 at the outlet. Multiplying this by 0.70779 which represented the portion of the Greenhill Lake watershed drained by the inlet stream, gave an annual inflow volume of 1,761,667 m^3.

Mean P measured in the inlet stream was 91.31 mg/m^3.

1,761,667 m^3 X 91.31 mg/m^3 = 160,857,814 mg = 160.86 kg contributed via the inlet stream.

P from land runoff to the stream = 6.0 kg/km^2/yr x 3.27 km^2 = 19.62. Input from piggery = 160.86 - 19.62 = 141.24 kg

(b) Input from land runoff directly to the lake = 1.15 km^2 X 6.0 kg/km^2/yr = 6.90 kg.

(c) Contribution from precipitation falling directly on the lake = 0.012 mg/l (average concentration in rainfall) X 198,300 m^2 (surface area of lake) X 0.8721 m (precipitation at Mapleton November 1, 1986 to October 31, 1987) = 2,075,249 mg = 2.08 kg.

(d) The estimated P contribution from dwellings was calculated the same as in the previous year and equalled 0.47 kg.

(e) Total annual supply to the lake =
1. inlet stream 160.86 kg
2. land runoff directly to lake 6.90
3. precipitation on lake 2.08
4. domestic 0.47
TOTAL 170.31 kg

3. Annual Export of P
(a) 2,488,968 m^3/yr X 61.86 mg/m^3 (ave.P at outlet) = 153,967,561 mg =153.97 kg/yr. *

4. Predicted Spring P Concentration

$$[P] = \frac{L(1-R)}{zp}$$

L = supply of P / unit of lake area
R = retention coefficient
z = mean depth
p = flushing rate (times/yr)

$$L = \frac{170.31 \text{ kg}}{198{,}300 \text{ m}^2} = .00085885 \text{ kg/m}^2 = 858.85 \text{ mg/m}^2$$

$$R = 0.426 \exp(-0.271\, qs) + 0.574 \exp(-0.00949\, qs)$$

qs= lake outflow volume/surface area= $\frac{2{,}488{,}968 \text{ m}^3}{198{,}300 \text{ m}^2}$ = 12.552

$$R = 0.426 \exp(-0.271 \times 12.552) + 0.574 \exp(-0.00949 \times 12.552)$$

$$R = 0.426 \exp -3.402 + 0.574 \exp -0.119 = 0.014 + 0.510 = 0.524 \quad z = 3.082 \text{ m}$$

$$p = \frac{\text{outflow volume}}{\text{lake volume}} = \frac{2{,}488{,}968 \text{ m}^3}{611{,}237 \text{ m}^3} = 4.072 \text{ times/yr.}$$

$$[P] = \frac{858.85\,(1-0.524)}{3.082 \times 4.072} = \frac{858.85(0.476)}{12.550} = 32.57 \text{ mg/m}^3 =$$

0.033 mg/l

The median concentrations in the lake were 0.027 mg/l on May 6, 1987 and 0.022 mg/l on May 15, 1987.

* Domestic wastewater was noted entering the outlet stream above the sampling point. It is not known to what extent this may have affected the estimate of P export.

Instead of using average flows and P concentrations, daily P loads were calculated and added to obtain an annual P loading. This resulted in 122.00 kg/yr via the inlet steam and 121.05 kg/yr leaving via the outlet. Total annual P loading was then:

1.	inlet stream	122.00 kg
2.	land runoff	6.90
3.	precipitation	2.08
4.	domestic	0.47
	Total	131.45 kg

$$[P] = \frac{L\,(1-R)}{zp}$$

$L = \frac{131.45\ kg}{198{,}300\ m^2} = 0.000662884\ kg/m^2 = 662.88\ mg/m^2$

$R = 0.524$

$z = 3.083\ m$

$p = 4.072$ times/yr.

$$[P] = \frac{662.88\,(0.476)}{12.550} = 25.14\ mg/m^3 = \underline{0.025\ mg/l}$$

5. Predicted P Assuming Piggery Source Removal

1. inlet stream - P contribution would only be from land runoff, thus, 3.27 km^2 in stream watershed X 6.0 $kg/km^2/yr.$ = 19.62 kg/ P from piggery = 122.00 - 19.62 = 102.38 kg.

2.	land runoff, remainder of watershed	6.90
3.	precipitation	2.08
4.	domestic	0.47
	Total	29.07 kg/yr

$L = \frac{29.07\ kg}{198{,}300\ m^2} = 0.000146596 = 146.60\ mg/m^3$

$$[P] = \frac{146.60(0.476)}{12.550} = 5.56\ mg/m^3 = 0.006\ mg/l$$

6. Response Time

(a) Response time - time required for lake to reach a state of equilibrium after a change in P loading

t 1/2 - time required for P concentration to move half way from an original steady state concentration to a final steady state concentration. Three to five times the t 1/2 indicate the response time.

$$t\ 1/2 = \frac{0.69}{(p + \frac{10}{z})} = \frac{0.69}{4.072 + \frac{10}{3.082}} = \frac{0.69}{7.317} = 0.094 \text{ yr}$$

3t 1/2 = 0.28 yr

5t 1/2 = 0.47 yr

A new equilibrium was predicted to be reached in 0.28 to 0.47 year after a change in the P supply. Response time depends on the flushing rate and average depth, and thus, remains the same regardless of the magnitude of change in P loading.

7. Determination of Internal Loading

(a) First Method

P in Lake	largest amount	30.26kg	July 16, 1987
	smallest amount	6.72 kg	June 2, 1987

Net gain 30.26 - 6.72 = 23.54 kg

P int = P in lake - (Pi-Po)
P int - internal phosphorus loading
P in lake - change in phosphorus mass in lake between June 2 and July 16, 1987
Pi - total P input June 2 - July 16
Po - P loss via outlet June 2 - July 16.

sum of flows, Hayden Brook, June 2-July 16, 1987 = 2.892 cms
2.892 cms/45 days = 0.0643 cms average
0.0643 X 0.71296 = 0.0458 ave cms at outlet X 60 sec X 60 min X 24 hr X 45 days = 178,239 m^3
178,239 X 0.70779 = 126,156 m^3 at inlet
average P inlet = 0.1188 mg/l = 118.8 mg/m^3
average P outlet = 0.0382 mg/l = 38.2 mg/m^3
Pi = 126,156 m^3 X 118.8 mg/m^3 = 14.99 kg
Po = 178,239 m^3 X 38.2 = 6.81 kg
P int = 23.54 - (14.99-6.81) = 23.54 -8.18 = 15.36 kg

(b) Second Method

Based on daily flows and P concentrations, Pi = 12.88 kg and Po = 7.11 kg

P int = P in lake - (Pi-Po)
P int = 23.54 - (12.88-7.11) = 23.54-5.77 = 17.77 kg.

While internal P loading was considered to be nearly non-existent in 1986, it appears that P had accumulated to the point that internal phosphorus loading was beginning to take place in 1987. If external sources are not soon controlled, internal P loading could slow recovery should P inputs be reduced in the future.

8. Conclusions and Discussion

(a) Using two methods of calculation, the P supply to Greenhill Lake from November 1, 1986 to October 31, 1987 was estimated to be 170.31 kg and 131.45 kg. Of this, 141.24 kg (83 percent of total) and 102.38 kg (78 percent of total) were calclulated to be contributed by the piggery located on the drainage of the inlet stream. When compared to the previous year's total of 311 kg, the present loading is considerably less. This probably resulted from decreased precipitation during the study period (75 percent of normal November 1, 1986 to October 31, 1987 as opposed to 93 percent of normal, November 1, 1985 to October 31, 1986) and hence, less transport of P to the lake. This was further evidenced by P concentrations in the lake which remained near the critical level of 0.025 mg/l for much of the summer but increased sharply in September and October when rainfall also increased.

(b) Concentrations of P in Greenhill Lake at spring turnover were predicted to be 0.033 and 0.025 mg/l depending on the method of calculation used. Thus, even with a reduced P loading the predicted concentrations in the lake were still excessive.

(c) In the absence of P from the piggery, concentrations in the lake were predicted to decline to 0.006 mg/l.

(d) The time to reach a new equilibrium P concentration after a change in P supply was calculated to be 0.28 to 0.47 years. The somewhat longer time as compared to 1986 resulted from the lower flushing rate due to less precipitation.

(e) Calculations indicated that the lake may have been in the initial stage of internal P loading. If loadings from external sources continue at measured levels, recovery time could extend beyond that predicted.

LITERATURE CITED

Dillon, P.J. and F. H. Rigler 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. Jour. Fish. Res. Board of Canada. 32(9): 1519-1531.

N.B. Dept. of Municipal Affairs and Environment. 1987. Phosphorus modelling Greenhill Lake. Tech. Report Series No. T-8701. Environmental Sciences Branch, Fredericton. 14 pp.